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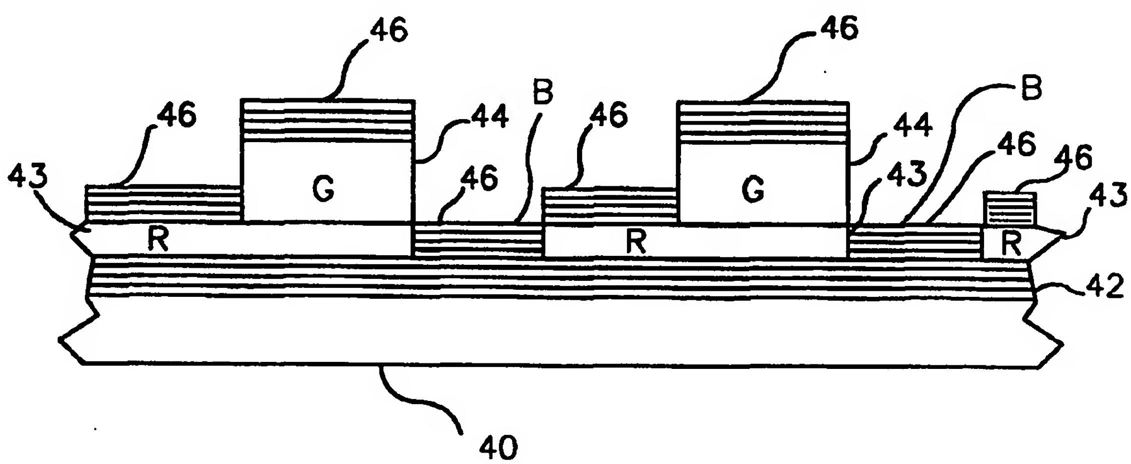

(57) Abstract

A color filter array for use in such devices as liquid crystal displays. The filter is of an interference type which uses a single cavity Fabry-Perot type filter design. In each pixel area, filters are created for red, green and blue light with each filter sharing a common broadband dielectric mirror. The differences between the filters lie in the tuning thickness between the mirrors for each filter. The use of the common broadband dielectric mirror simplifies the processing required to fabricate mosaic arrays of RGB filters, since filters share common construction module mirror stacks, which can be applied as blanket coatings, with mosaic pixel patterning and filter tuning achieved by the thickness and boundary definition of a central spacer layer.

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COLOR FILTER ARRAY

FIELD OF THE INVENTION

The present invention relates to color filter arrays, and more specifically to color filters using interference filters.

BACKGROUND OF THE INVENTION

Liquid crystal mosaic display technology is being developed as a possible successor to color cathode ray tubes (CRT's) in many applications. This technology offers important advantages such as higher reliability along with reduced power, size and weight.

While different types of color liquid crystal display devices exist, such devices generally include two spaced panels which define a sealed cavity filled with a liquid crystal display material. A transparent common electrode is formed inside the defined cavity on one of the glass panels. Individual electrodes, also on the inside of the defined cavity, are formed on the other glass panel. Each of the individual electrodes has a surface area corresponding to the area of one, or part of one, picture element. Each picture element is too small to be easily seen by the unaided human eye. If the device is to have color capabilities, it must also include color filters with red, green and blue color areas. Each color area is aligned with one of the electrodes. Each set of red, green, and blue color areas is grouped into a triad, repetitive stripe, or other consistent pattern within the picture element.

In a typical LCD, each of the individual electrodes can be addressed by means of a thin film transistor. Depending upon the image to be displayed, one or more of the electrodes is energized during the display operation to allow full light, no light, or partial light to be transmitted through the color filter area associated with the electrode. The image perceived by the user is a blending of colors formed by the transmission of light through adjacent color filter areas.

In many cases the LCD may be backlighted by locating a light source on the opposite side of the display, away from the viewer. Alternatively, the display may include a reflective layer at its rear surface and rely on the light source located on the same side of the display as the viewer.

Color filters for use on such devices have been fabricated using a number of different approaches. One approach has been to spin or deposit a light sensitized

adhesive film onto the glass panel. The film is then patterned in three sequential steps. During each step, dye of a specific color is applied to the predetermined regions of the film. According to another approach, organic pigments are deposited by vacuum evaporation. These pigments are then photolithographically patterned by conventional lift-off techniques. According to still another approach, a dyed and patterned stretched film material is used to create an internal color polarizing filter.

Another type of color filter is of the interference type. Optimum performance is obtained using multilayer thin film dielectric color filters, which are more efficient than the alternative dye filters, do not bleach or degrade with time, and are relatively hard. The conventional method for producing patterned filters of this type is to use a lift-off technique to pattern two or more thin film dielectric stacks of well-defined transmission characteristics. The stacks are typically made of dielectric materials such as ZnS/MgF_2 or the harder, more durable, and optically stable materials SiO_2/TiO_2. In order to provide suitable transmission characteristics for individual colors, the dielectric materials are assembled according to a precise design which specifies each layer thickness and refractive index. In one method in particular, filter stacks are deposited sequentially and uniformly over a glass substrate. A selective etching or lift-off procedure is then performed on the filter stacks to separate the stack filters and thus define pixel color location. While this sequence is simpler and less expensive to produce than brute force separate mapping of discrete filter designs in pixel zones, it does not appear possible to achieve the true color separation filters necessary in LCD displays for full range color gamut.

SUMMARY OF THE INVENTION

The invention herein is a mosaic color filter array for use in such devices as a liquid crystal display. An array of interference filters is disclosed which achieves color separation through the use of single cavity Fabry-Perot type filters. Specifically, common broadband dielectric mirrors are used for all the color filters with tuned spacer layers positioned between the mirrors in order to control the transmission of a particular wavelength of light.

The method of fabricating the filter array comprises the steps of first providing a transparent glass substrate. On the substrate a first layer sequence, M1, of predetermined reflectance is deposited. M1 is comprised of alternating layers of high

(e.g., TiO_2) and low (e.g., SiO_2) index of refraction dielectric materials. A transparent spacing layer of known index of refraction is then deposited over M1 and its thickness is tuned at individual pixel positions for a mosaic layout of red, green and blue filters. A second reflective layer, sequence M2, which may be similar but not necessarily identical to M1, is then deposited over all the pixel positions, thus creating an array of single cavity Fabry-Perot type filters. The bandwidth and peak transmittance properties of these Fabry-Perot filters are determined by the reflectance properties of M1 and M2, while their tuning (i.e., center wavelength) is determined by the optical thickness of the spacer layer.

The advantage of the above described process is that common first and second reflective layers can be used at all pixel positions. This fabrication sequence is simpler and less expensive to produce than separate mapping of discrete filters designed into three pixel zones.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross section of an embodiment of a liquid crystal display.

Figure 2 is a possible pattern for mapping pixels positions.

Figure 3 is a cross section of a portion of the color filter array.

Figure 4 is a graph showing the spectral characteristics of the red filter.

Figure 5 is a graph showing the spectral characteristics of the green filter.

Figure 6 is a graph showing the spectral characteristics of the blue filter.

Figure 7 is a graph showing the spectral characteristics of a second embodiment of the color filter array.

Figure 8 is a graph showing the spectral characteristics of a third embodiment of the color filter array.

Figures 9a-9d show the sequence of depositing reflective layers, photolithographic masking, and transparent space tuning layers.

Figures 10a and 10b show the creation of the color filter array using standard lift-off technique.

PREFERRED EMBODIMENT OF THE INVENTION

The invention described herein is a mosaic color filter array. Although this array can be used with T.V. cameras and a variety of projection devices, it is described herein in relation to a liquid crystal display (LCD).

Figure 1 is a cross section of an embodiment of a liquid crystal display in which the present color filter array could be incorporated. The LCD includes a backlight 12 which transmits white light to components which are positioned between rearward glass panel 11 and forward glass panel 22. These components include the color filter array 14, thin film transistor 16, liquid crystal 18, and absorptive filters 20. In the present embodiment, the color filter array 14 acts to allow passage of light of a particular wavelength while retroreflecting light of all other wavelengths into a chamber which encloses the backlight 10. The liquid crystal in combination with the thin film transistors act as an on/off switch for the passage of light so that when the switch is on, the liquid crystal is transparent and allows all wavelengths of light to pass. When it is off it is opaque allowing no wavelengths to pass. The absorptive filters 20 absorb all wavelengths of light except those of a particular pass band. The combination of the reflective color filter array with the absorptive color filters acts to improve color saturation of the display conserve light energy normally lost by absorption in conventional construction, and maintain good color at off normal viewing angles. This combination of color filters is described in more depth in international patent application number PCT/US94/02668, entitled "Patterned Dichroic Filters for Color Liquid Crystal Display Chromaticity Enhancements", which is hereby incorporated by reference.

As seen in Figure 1, different portions of the liquid crystal display allow different wavelengths of light to pass. In the example shown, the colors of red, green and blue are allowed to pass through particular portions of the liquid crystal display. A plan view of color pixels in a typical color filter array are shown in Figure 2. This typical mosaic layout allows for the viewing of full color in liquid crystal displays. As is seen the array is laid out in separate Blue 30, Red 32, and Green 36 pixel positions.

The invention herein is focused on color filter array 14. The design of such optical interference filters is common in the optics industry. The filters can be fabricated from a variety of refractory inorganic evaporated or sputtered thin films. The filter typically consists of three layers, the second layer interposed between a first and third layer. The first and third layers are highly reflective, slightly transmitting film such as silver. The second or spacer layer is a dielectric layer such as zinc sulfide. The thickness of the spacer layer determines the wavelength of the output light and hence the color. This type of filter is more commonly known as a Fabry-Perot optical

interference filter with the spacer layer thickness of the filter adjusted to provide transmission of a particular color. To insure that the transmitted light has a narrow pass band and that there is minimum transmission outside of the passband frequency, the reflecting layer should have a reflectivity close to unity. A higher performance alternative to single layer metal mirrors (which absorb some of the light) is to use low absorption all-dielectric layers arranged in properly designed thickness sequences to form the Fabry-Perot cavity mirrors. The simplest all-dielectric mirror designs are just quarter wavelength tuned stacks (i.e., the optical thickness of each layer is a quarter wavelength of the wavelength for peak reflectance) of alternating high and low refractive indices. The result of this is that alternating layers of materials such as titanium dioxide (TiO_2) and silicon dioxide (SiO_2) can be used to manufacture the entire filter.

Shown in Figure 3 is a cross sectional view of the present color filter array. Shown in particular is the repeating nature of the red, green and blue filters for each pixel position within the array. The filter is comprised of a transparent glass substrate 40 with a first mirror stack 42 disposed thereon. As was described above, first mirror stack 42 is comprised of alternating layers of TiO_2 and SiO_2. This first mirror stack has a uniform thickness for the entire filter array. On top of the first mirror stack 42 are tuned spacer layers 43 and 44, both made of SiO_2. The tuned spacer thicknesses are dependent on the type of color filter desired. On top of the first mirror stack 42 and tuned spacer layers 43 is second mirror stack 46. In this embodiment of the invention the second mirror stack 46 is of the same composition and thickness as the first mirror stack 42.

As was described above, the basic design for each of the three color filters within the array is known as a single cavity Fabry-Perot filter. A Fabry-Perot filter is simply a tuned cavity structure of two mirrors separated by a spacer layer. In this filter, resonance peaks occur when the spacer thickness is an integer multiple of one half the wavelength of resonant frequency. So if the same mirror stack is used for both mirrors, the basic filter designs are then of the form:

$$M|\frac{p\lambda_{red,green,\ or\ blue}}{2}|M$$

where p is an integer, M denotes the thickness and structure of the mirror stacks, and λ is the wavelength of either the red, or blue light. In this embodiment M = $1.1(HLH).8(LH)^2$, where L denotes a quarter wave optical thickness (QWOT) of SiO_2 and H, a QWOT of TiO_2 at a wavelength of 550 nm (i.e., the middle of the visible spectrum). Note that the QWOT of a material of index refraction n, corresponds to a physical thickness of $\lambda/4n$. So at λ =550 nm, H is equal to 57 nm and L is equal to approximately 92 nm.

The red filter is obtained from a layer structure M/1.2L/M or $1.1(HLH).8(LH)^2/1.1(HLH)/1.1(HLH).8(LH)^2$. A green filter is obtained from the layer structure M/2.5L/M, or $1.1(HLH).8(LH)^2/2.5L1.1/(HLH).8(LH)^2$. In the green case and in the red filters, the harmonic spacer thickness is 1.2L and 2.5L, respectively. In this embodiment, the blue filter does not have the tuned spacer layer and is obtained from a structure that looks like $1.1(HLH).8(LH)^2 1.1(HLH).8(LH)^2$. This design has the primary advantage of achieving color separation without optical absorption loss and thus greatly improved efficiency.

Figures 4-6 show the spectral characteristics for the red, green and blue filter designs, respectively. In each figure a graph is shown of the transmissibility of a particular color filter versus the wavelength of light. In each case the passband is narrow enough to achieve true color separation, but wide enough to help mitigate the shift to shorter wavelengths with viewing angle, which all interference coatings are subject to.

Should filters with different optical characteristics be required for a particular application, the approach described herein offers the advantage of flexible adaptability. For example, if filters of narrower/wider spectral bandwidths are needed, the second embodiment of:

M=1.1H1.1L1.1H.7L.7H.7L

Red = M^2

Green = M/1.5L/M

Blue = M/L/M

whose performance is shown in Figure 7, and the third embodiment

M=1.1H1.1L.8H.8L

Red = M/1.8L/M

Green = M/1.2L/M

Blue = M/1.5L/M

whose performance is shown in Figure 8, illustrate how the filter optical performance can be tailored as required

One method of constructing the color filter array is depicted in Figures 9 and 10 and is as follows:

The procedure described below is a conventional lift-off procedure which is used in the creation of integrated circuit devices. The lift-off technique is extremely useful for fine geometries and when perpendicular sidewalls are required.

Figure 9 shows the glass substrate 40 which the color filter is constructed upon. In the first step shown in Figure 9b the first mirror stack 42 is blanket coated over the whole substrate 40. The mirror stacks are comprised of alternating layers of SiO_2 and TiO_2 using the thicknesses described above. In accordance with using conventional lift off techniques for constructing the first embodiment, blue pixel locations are masked off photolithographically leaving areas open in the red and green pixel locations. The blue photolithographic masking 60 is deposited right on the mirror stack 42. As seen in Figure 9b a tuned spacing layer 44 made of SiO_2 is deposited over the blue masking 60 and the first mirror stack 42 at the red tuning thickness. In manufacturing the third embodiment, a spacing layer is deposited over the mirror stack at the green tuning thickness before masking is laid. Returning again to the first embodiment, as shown in Figure 9c, pixel areas are masked off for the red filters with masking 62 leaving only the green pixel areas exposed. In the next section in Figure 9d, a second spacing layer 44 is disposed over the red masking 62 and the first spacing layer 43. The combined thicknesses of layers 44 and 43 are sufficient to create the Fabry-Perot cavity for green light once the filter array is fully constructed.

Figures 10a and 10b show the final steps in the lift-off process. In Figure 10a, once the array is immersed in warm acetone or a solvent, the red photorestive coating ·r the blue and red filters swell and portions of the tuned spacer layer are removed. In :e final step shown in Figure 10b, a second filter stack 46 is then formed over the entire substrate 44 using a vacuum deposition process. As can be seen, three distinct filter thicknesses have been created in a repetitive fashion. The first area has only spacer layer 43, the second area has the combination of spacer layer 43 and 44, and the last area

has neither spacer layer 44 or 43. Although a conventional lift-off technique is used herein to describe the construction of the color filter array, it would be obvious to one skilled in the art that other techniques such as photo masking along with etching could also be used to construct the filter. Also, it would be obvious to use other materials such as ZnS and MgF_2 to construct the filter array. Both etching and lift-off techniques are well known in the art.

The foregoing is a description of a novel and nonobvious color filter array. The applicant does not intend to limit the invention through the foregoing description, but instead define the invention through the claims dependent hereto.

CLAIMS

1. A method of fabricating a color filter array comprising the steps of:

providing a transparent glass substrate with first and second sides;

depositing a first reflective layer sequence of known thicknesses and compositions on the first side of the substrate;

depositing a transparent spacing layer with a known index of refraction on the first reflective layer;

identifying a plurality of color pixel locations on the transparent glass layer;

tuning the thickness of the transparent glass layer at each of the plurality of pixel locations; and

depositing a second reflective layer sequence of known thicknesses and compositions over the transparent glass layer.

2. The method of fabricating a color filter array of Claim 1 wherein the color filter array is incorporated into a liquid crystal display.

3. The method of fabricating a color filter array of Claim 1 wherein the first and second reflective layer sequences are comprised of alternating layers of TiO_2 and SiO_2.

4. The method of fabricating a color filter array of Claim 1 wherein the transparent glass layer is constructed of SiO_2.

5. The method of fabricating a color filter array of Claim 1 wherein the pixel positions are defined by photolithographic masking.

6. The method of fabricating a color filter array of Claim 5 wherein the step of tuning the thickness of the transparent layer is performed using lift-off and photorestive stripping.

7. The method of fabricating a color filter array of Claim 1 wherein the pixel positions for red, green, and blue are identified.

8. The method of fabricating a color filter array of Claim 7 wherein the first and second reflective layers are tuned so as to provide an interference filter for the color blue without including the transparent glass tuned layer.

9. The method of fabricating a color filter array of Claim 7 wherein the first and second reflective layers are tuned so as to provide an interference filter for the color red without including the transparent glass tuned layer.

10. A color filter array comprising:

a transparent glass substrate;

a first reflective layer sequence disposed on said glass substrate;

a plurality of tuned spacing layers disposed on said first common reflective layer at predetermined positions; and

a second reflective layer sequence disposed over said plurality of tuned spacing layers so as to create a plurality of Fabry-Perot single cavity color filters.

11. The color filter array of claim 10 wherein the color filter array is incorporated into a liquid crystal display.

12. The color filter array of claim 10 wherein the first and second reflective layer sequences are comprised of alternating layers of TiO_2 and SiO_2.

13. The color filter array of claim 10 wherein the tuned spacing layers are comprised of SiO_2.

14. The color filter array of claim 10 wherein the Fabry-Perot single cavity color filters are created for red, green, and blue.

15. The color filter array of claim 14 wherein the second reflective layer is deposited directly on said first reflective layer in order to provide the blue color filter while the plurality of tuned spacing layers are required for the red and green filters.

16. The color filter array of claim 14 wherein the second reflective is deposited directly on said first reflective layer in order to provide the red color filter while the plurality of tuned spacing layers are required for the blue and green filters.

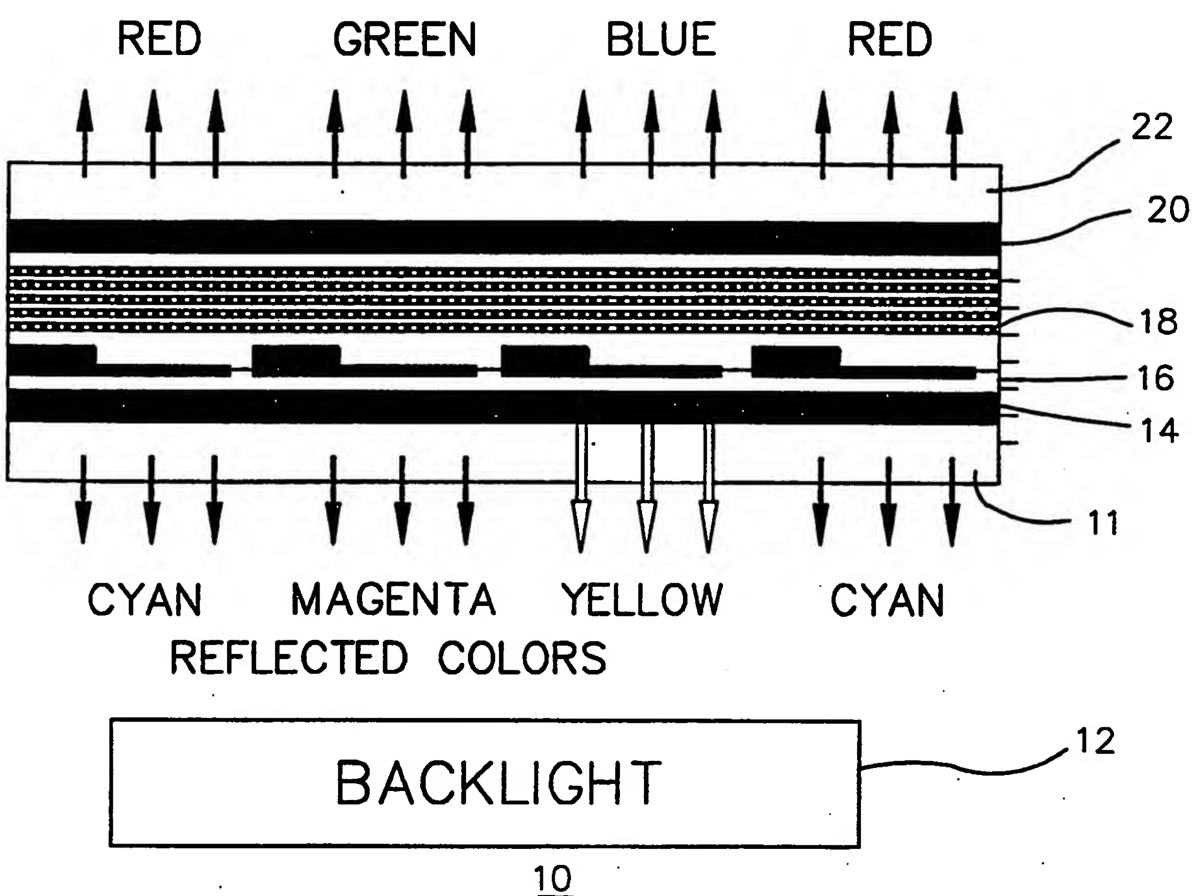

RED
GREEN
BLUE
RED
22
20
18
16
14
11
CYAN
MAGENTA
YELLOW
CYAN
REFLECTED COLORS
BACKLIGHT
12
10

Fig. 1

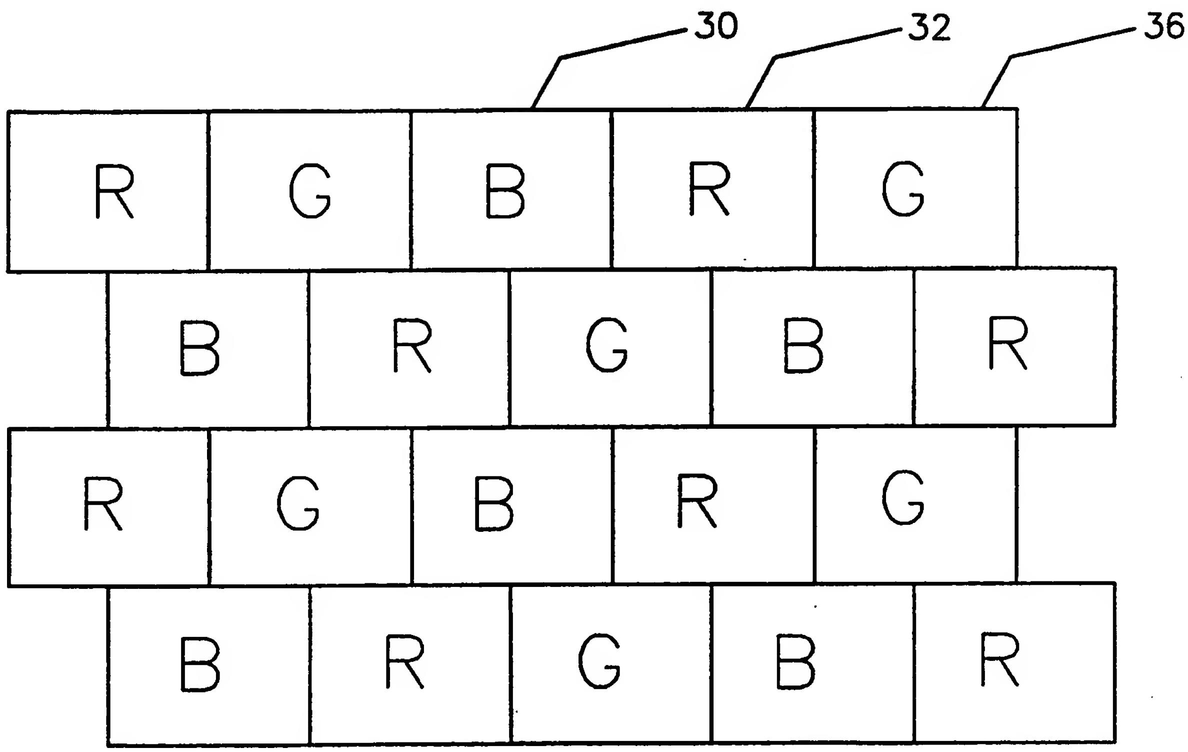


Fig.2

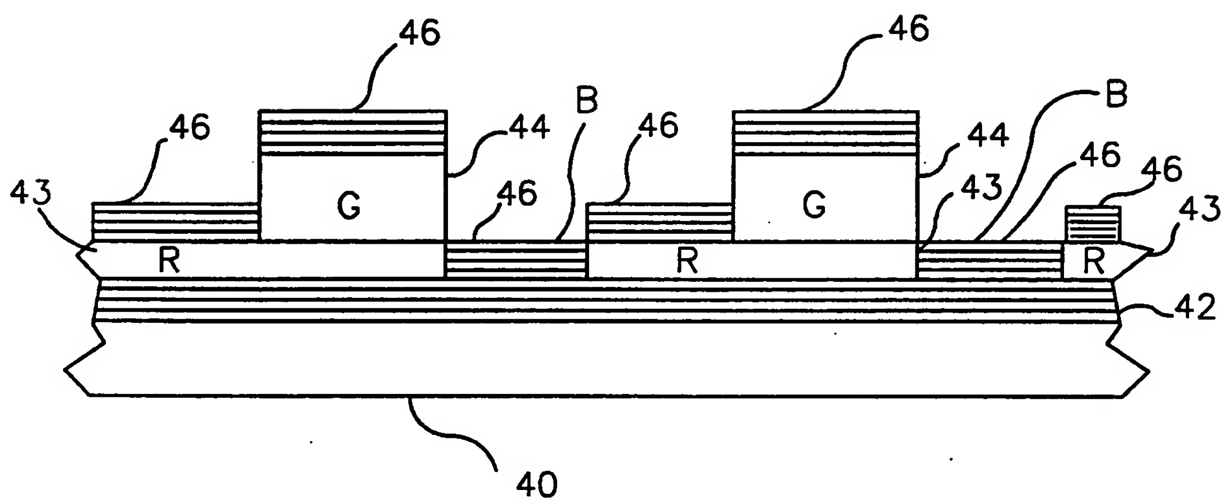
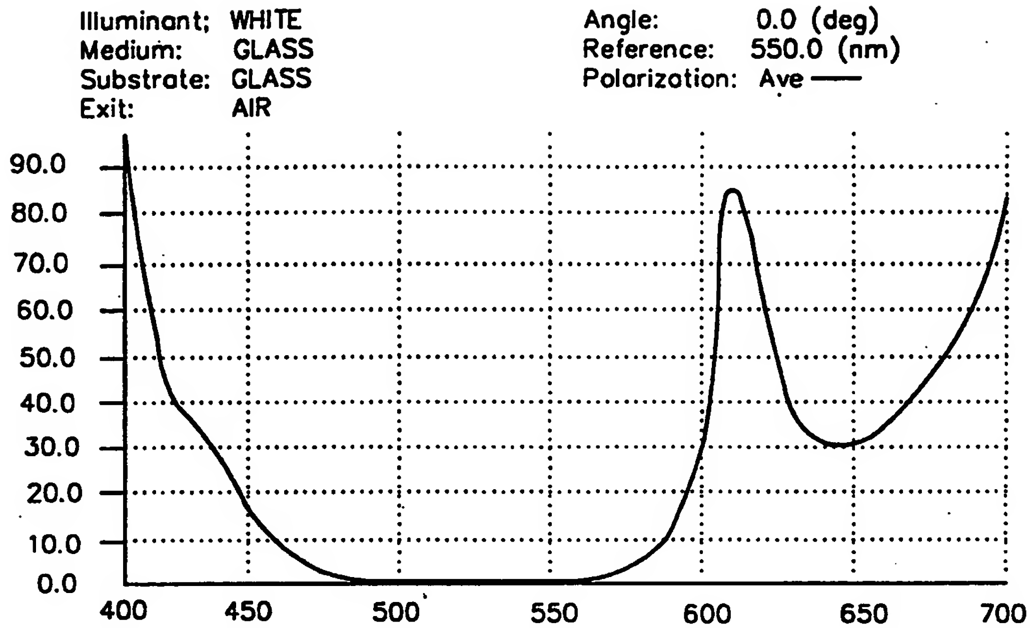


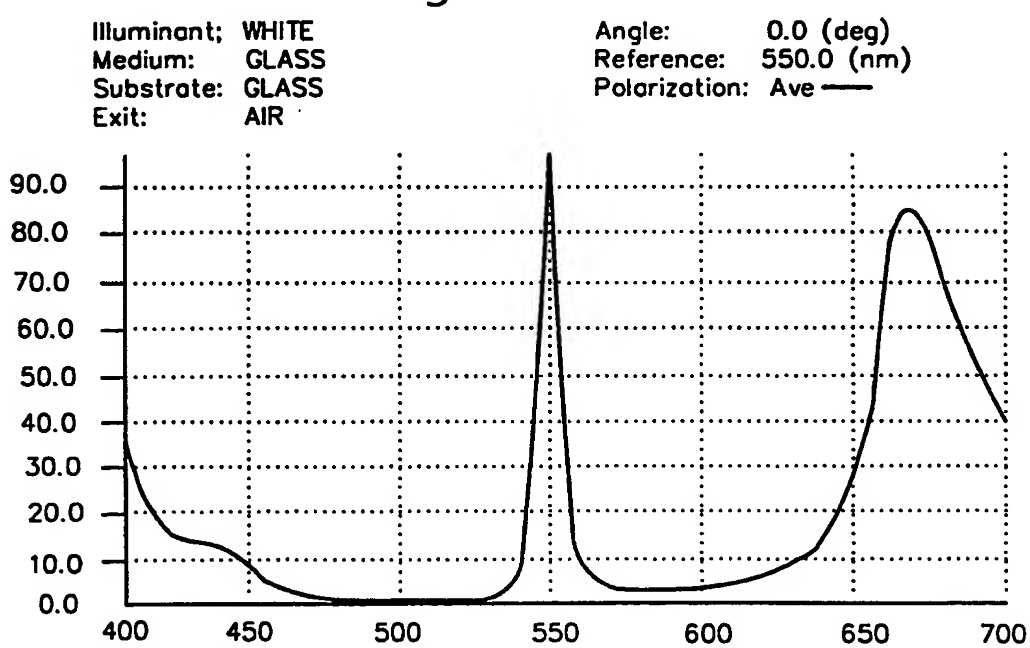
Fig. 3



Transmittance (%) vs Wavelength (nm)

Design: [incident medium n=1.5]/mirror/1.2L/mirror/[glass substrate]/[air]

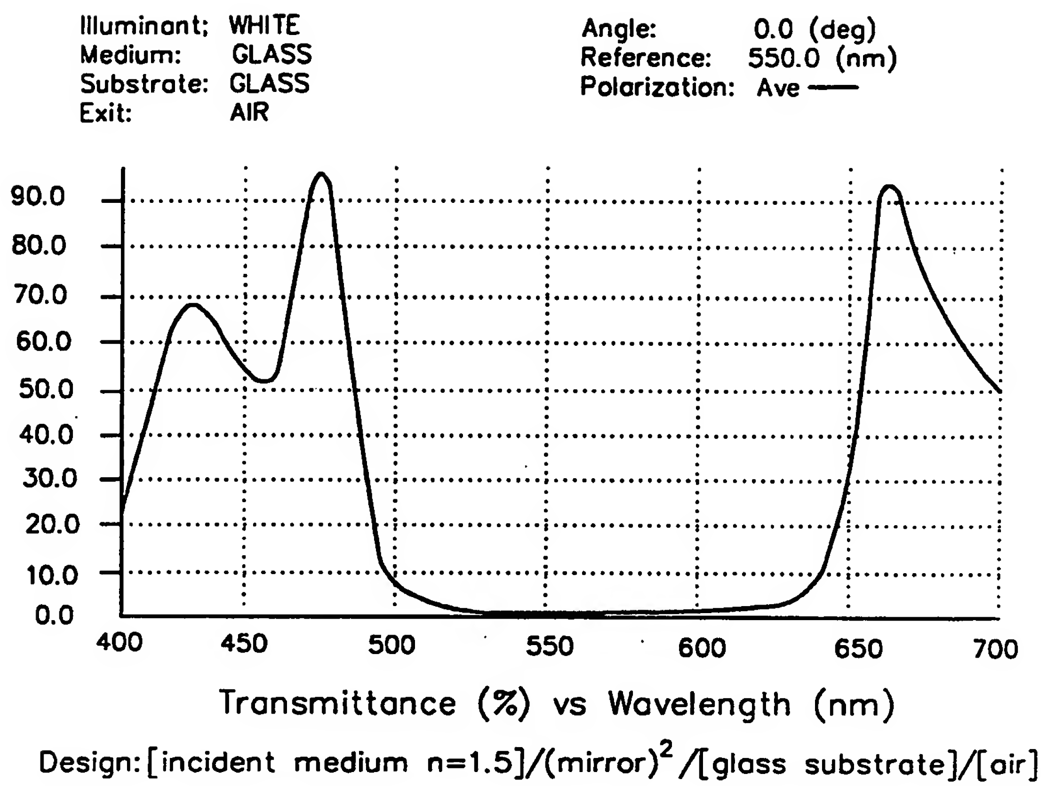
Fig. 4



Transmittance (%) vs Wavelength (nm)

Design: [incident medium n=1.5]/mirror/2.5L/mirror/[glass substrate]/[air]

Fig. 5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Substrate: GLASS
Exit: AIR
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Reference: 550.0 (nm)
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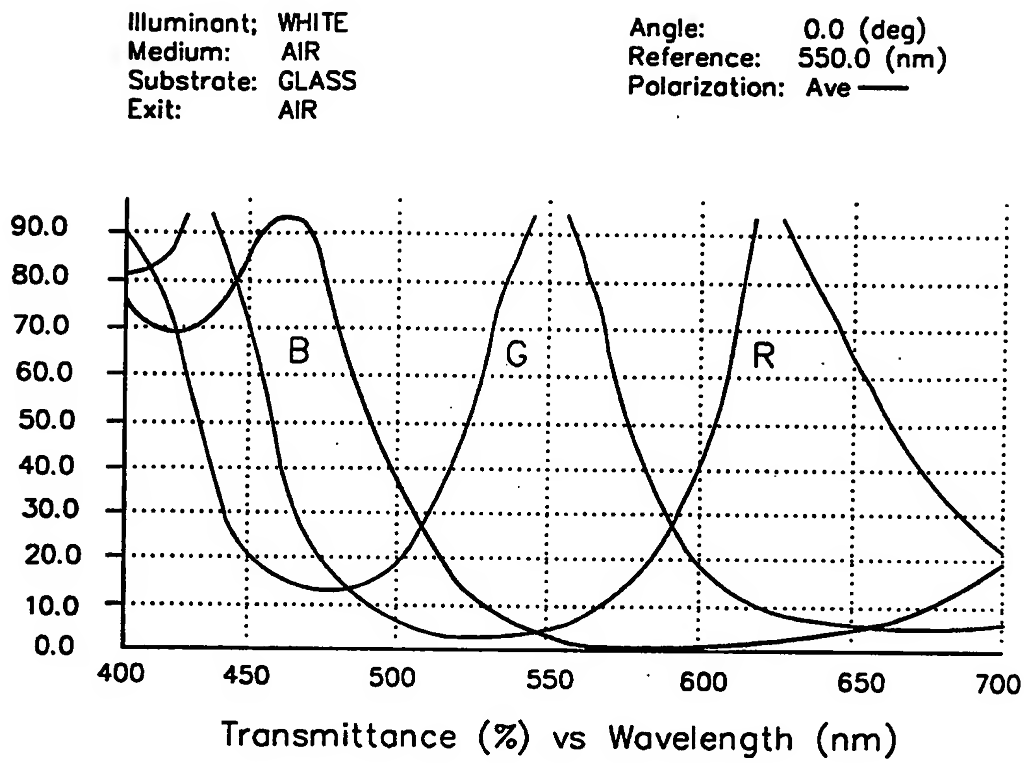
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
400
450
500
550
600
650
700
Transmittance (%) vs Wavelength (nm)
Design: [incident medium n=1.5]/(mirror)^2/[glass substrate]/[air]

Fig. 6



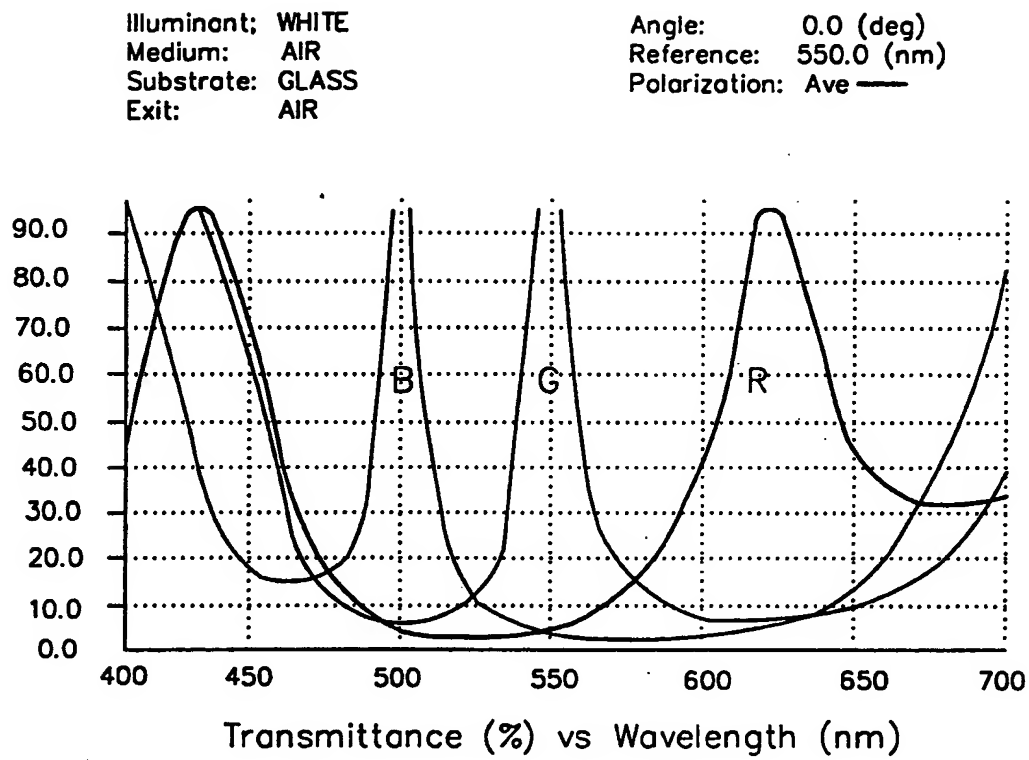
M = 1.1H1.1L.8H.8L

Red: M/1.8L/M

Green: M/1.2L/M

Blue: M/1.5L/M

Fig. 7



M = 1.1H1.1L1.1H.7L.7H.7L

Red:	M^2
Green:	M/1.5L/M
Blue:	M/L/M

Fig.8

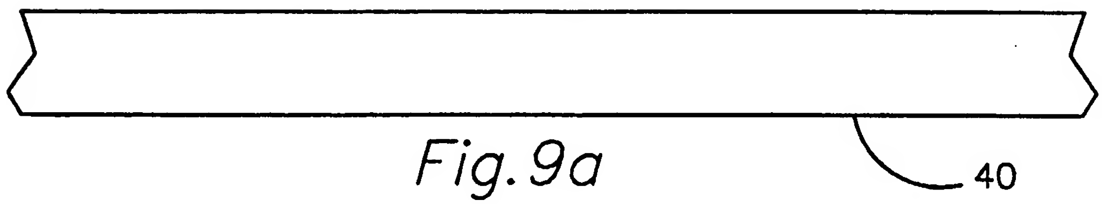


Fig. 9a

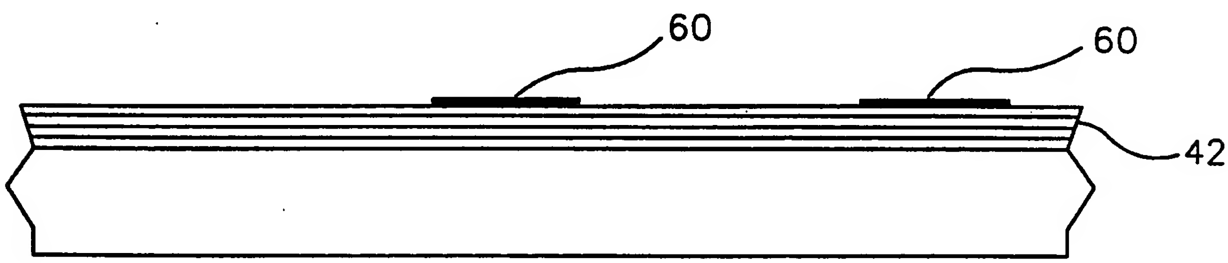


Fig. 9b

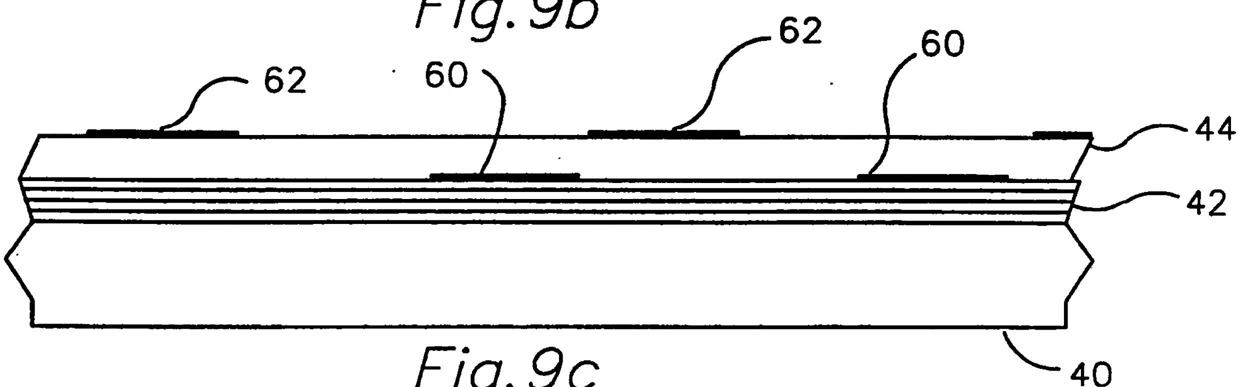


Fig. 9c

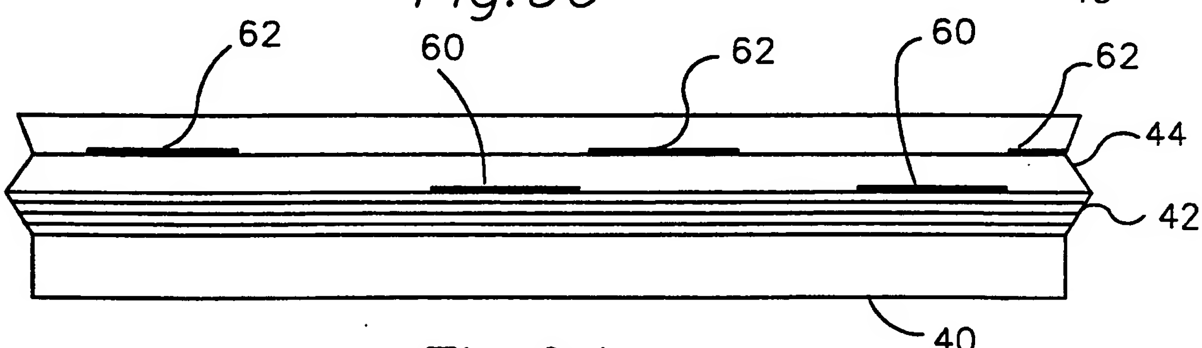


Fig. 9d

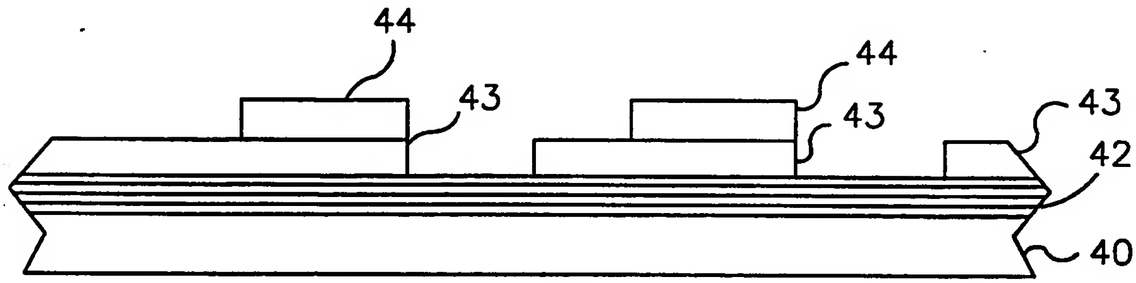


Fig. 10a

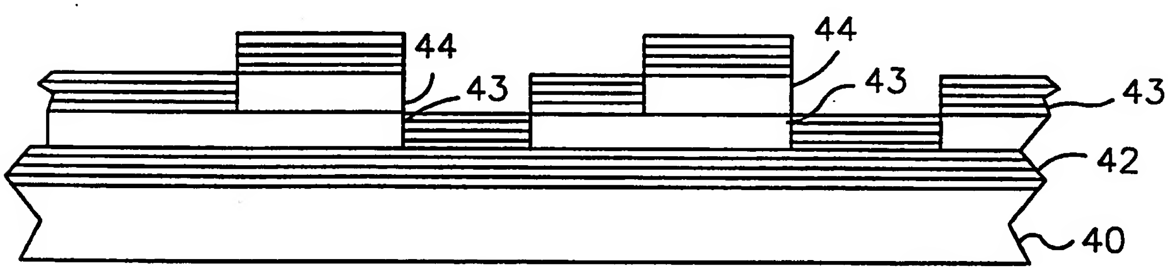


Fig. 10b

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 94/14120

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02B5/20 G02F1/1335

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02B G02F G01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US,A,2 769 111 (SADOWSKY) 30 October 1956	1,7,10, 14
A	see the whole document ---	4,5,13
X	US,A,4 979 803 (MCGUCKIN ET AL) 25 December 1990	1,4,7, 10,13,14
A	see column 1 - column 4 ---	5,6
X	US,A,4 822 998 (YOKOTA ET AL) 18 April 1989 see the whole document ---	1,4,10, 13

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"&" document member of the same patent family

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Date of the actual completion of the international search	Date of mailing of the international search report
16 March 1995	05.04.95

Name and mailing address of the ISA	Authorized officer
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Form PCT/ISA/210 (second sheet) (July 1992)

International Application No
PCT/US 94/14120

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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